

1 achieving the proper vacuum level, or may evaporate and be co-deposited with the
2 PVD coating material.

3 For the foregoing reasons, PVD coatings have generally been limited to
4 substrates having smooth or non-porous surfaces, or surfaces that can be made smooth
5 or non-porous. Thus, PVD coatings have not been used in many otherwise suitable
6 applications. For example, certain porous substrates such zinc, brass, steel, aluminum
7 and tin are desirable in many applications because they are relatively inexpensive.
8 Methods have therefore been devised to "level" the surface of rough or porous
9 substrates. Such "leveling" methods in some instances seal the substrate surface,
10 providing improved corrosion resistance and promoting the adhesion of coatings to
11 the substrate surface.

12 One method that has been used to level porous or rough surfaces is by
13 polishing. PVD coated polished surfaces generally will be shiny, whereas an
14 unpolished or brushed part will provide a dull coating. Surfaces may be polished
15 using mechanical abrasion, chemical etching, or a combination of both.

16 Another method that has been used to level porous or rough substrates is to
17 plate the surface, generally with copper, nickel, and chrome, which also improves
18 corrosion resistance and provides a surface to which coatings adhere well. During the
19 plating operation, surface defects are filled in by the plated material, thus leveling the
20 surface. However, many plating operations, in particular chrome plating, are
21 expensive and may be harmful to the environment. In some cases, plating results in
22 an undesirable galvanic coupling.

23 In addition, substrate preparation processes are time consuming, expensive,
24 and labor intensive. Generally, only premium applications can justify either the high
25 cost of base materials such as stainless steel, or the costs of pre-finishing less
26 expensive substrates before metallizing.

27 Thus, there is need in the art for alternative methods for substrate preparation
28 and coating substrates.

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SUMMARY

The present invention is directed to a method of coating a substrate. The method involves providing a substrate having a surface, forming a polymeric coated surface by applying a layer of a polymeric precursor to at least a portion of the surface, polymerizing the polymeric precursor to form a polymerized layer, and applying a metal coating to at least a portion of the polymeric coated surface. The metal coating is applied under sub-atmospheric conditions. In some embodiments, the step of polymerizing the polymeric precursor includes elevating the temperature of the polymeric precursor to at least about 320°F. In some embodiments, the polymeric precursor is maintained at the elevated temperature for at least about 12 minutes. In some embodiments, the polymeric precursor is applied electrophoretically. In some embodiments, the polymeric precursor may be selected from the group consisting of acrylics, epoxies, urethanes, and combinations thereof.

Another embodiment of the method involves providing a substrate, coating at least a portion of the substrate with an electrophoretically applied polymeric precursor, polymerizing the polymeric precursor to form a first polymeric coating, and elevating the temperature of the polymeric coating to at least about 400°F for at least about 6 minutes.

Another embodiment of the method involves forming a polymeric coating from an electrophoretically applied polymeric precursor and applying a layer of metal over the polymeric coating. A layer of metal is then applied in a physical vapor deposition system.

Another embodiment of the invention is directed to an article having a surface. The article includes an electrophoretically applied first polymeric layer overlaying the surface. A metallic coating overlays the first polymeric coating. The thickness of the polymeric layers may range from about 1 millimeter to about 40 millimeters. The thickness of the metal layer may range from about 0.1 millimeter to about 3 millimeters.

BRIEF DESCRIPTION OF THE DRAWINGS

It should be understood that the drawings are provided for the purpose of illustration only and are not intended to define the limits of the invention. The foregoing and other objects and advantages of the embodiments described herein will become apparent with reference to the following detailed description when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a flow chart of a coating process according to one embodiment of the method;

FIG. 2 is a schematic of a substrate leveled using an electrophoresis coating;

FIG. 3 is a schematic of a leveled substrate coated with metal; and

FIG. 4 is a cross-section of a leveled substrate coated with metal and a second electrophoretically applied layer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present disclosure is directed to a method of leveling the surface of a substrate. The method involves applying a polymeric precursor to the surface of the substrate and heating the polymeric precursor at a predetermined temperature and for a predetermined period of time.

In another embodiment, the disclosure is directed to a method of applying a metallic coating to a substrate that involves leveling the surface of the substrate before applying the metal. The method involves leveling the surface of the substrate by applying a polymeric precursor to a surface of the substrate and heating the polymeric precursor at a predetermined temperature and for a predetermined period of time, followed by applying a metallic coating to the polymeric coated substrate.

The method of leveling the surface of the substrate will now be described. In some instances, the substrate may require some type of surface preparation, many of which are known in the art. For example, when using a metal substrate, it may be necessary to "debur," or remove high spots from the substrate. This may be accomplished using conventional metal finishing equipment. Alternatively, or in

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1 addition to deburring, the substrate may require etching, degreasing, cleaning, and the
2 like. Those of skill in the art will understand the type of surface preparation that may
3 be needed is based on the type of substrate selected and the condition of the substrate
4 surface.

5 After completion of surface preparation (when needed), a polymeric precursor
6 may then be applied to the surface of the substrate. There are many ways that the
7 polymeric precursor can be applied, many of which are known to those of skill in the
8 art. Any method of applying the polymeric material may be used in the present
9 method, provided that a uniform and relatively thin layer may be provided.

10 In preferred embodiments, the polymeric material may be applied using an
11 electrophoresis process. Electrophoresis is a preferred process due to the uniformity
12 of coating thickness provided, the speed of deposition of the coating, and the relatively
13 low environmental impact from the process. A typical electrophoresis process
14 involves providing a bath/cell containing a solution/suspension of a polymeric
15 material, immersing a substrate to be coated in the bath, and providing a DC charge
16 to the electrophoresis cell containing the substrate, preferably ranging from about 25
17 to about 300 volts. The substrate may be allowed to remain in the cell from about 5
18 to about 300 seconds. The substrate, when immersed in the electrophoretic cell under
19 electrical charge may be anodic or cathodic. The thickness of the polymeric coating
20 may range from about 1 μm to about 40 μm , depending upon the DC charge, the
21 length of time in which the substrate remains in the cell, and the type of polymer,
22 among other things.

23 After applying the polymeric precursor, the coated substrate may be
24 polymerized. Polymerization may be accomplished according to the manufacturer's
25 guidelines, followed by a separate heating step to remove any liquids in which the
26 polymeric precursor was dissolved, suspended, or mixed. However, a single heating
27 step to polymerize the polymeric precursor and remove the solvents is preferred for
28 ease of manufacturing. Removal of substantially all of the liquids from the polymeric
29 coating reduces or eliminates the possibility of any outgassing from the surface of the

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1 polymeric coating. Heating may be accomplished using a variety of methods,
2 including convection, infrared, ultraviolet, electron-beam, and others known to those
3 of skill in the art. The present embodiment involves elevating the temperature of the
4 substrate coated with the polymeric precursor to a temperature of about 135°C to
5 about 215°C in a convection oven, which is known in the art. The polymeric
6 precursor must be maintained at that temperature for about 30 seconds to about 120
7 minutes in order to polymerize the polymeric precursor and remove substantially all
8 of the liquids in which the polymeric precursor was dissolved, suspended, or mixed.
9 Those of skill in the art will recognize that the heating time and temperature may vary
10 depending upon, among other things, the type and thickness of the polymeric coating
11 as well as whether the polymeric precursor was polymerized.

12 Suitable substrates that may be used in conjunction with any of the methods
13 described herein include conductive substrates, non-conductive substrates, porous
14 substrates, non-porous substrates, and combinations thereof. The only limitation on
15 the type of substrate that may be used in conjunction with the methods is that it must
16 be able to withstand the heating temperatures of the method.

17 Suitable polymeric materials that may be used in conjunction with any of the
18 methods described herein include polyurethanes, acrylics, epoxies, and combinations
19 thereof. One polymeric material that may be used is a polyurethane available under
20 the product name of TECHNICLAD V-BASE® (trademark of Hawking Corporation
21 Ltd/Techniclad Ltd.). The polymeric material provides leveling properties along with
22 the ability to control thickness and reflectivity, which renders mechanical buffing
23 and/or abrading unnecessary. The reflectivity of the polymeric film may be accurately
24 controlled to be matte, gloss, or any degree in between. The corrosion resistance and
25 chemical resistance of substrates may be significantly improved with the application
26 of a layer of polymeric material.

27 Thus, one aspect of the present invention is the provision of a substrate having
28 a substantially level surface that does not outgas under the influence of a vacuum.

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1 Such a substrate facilitates the application of a metal coating using for example, PVD,
2 Chemical Vapor Deposition (CVD), evaporation, or other metal deposition methods.

3 Another aspect of the invention is a method of applying a metal coating to a
4 substrate. Preferably, the surface of the substrate does not outgas. In preferred
5 embodiments, the substrate is level or has been made level. However, the method of
6 applying the metal may be used on rough substrates provided they do not outgas.
7 According to the method, a suitable substrate is first selected. If necessary or desired,
8 surface preparation may be performed. After completion of surface preparation, a
9 polymeric precursor may then be applied to a surface of the substrate. Each of the
10 foregoing steps are performed as previously described.

11 Before applying the metal coating, the substrate must be free of residues,
12 fingerprints, oils, and any other contaminants which will affect the metal adhesion and
13 uniformity, as is well known to those of skill in the art. Therefore, in some instances,
14 it may be desirable or necessary to clean the substrate before applying the metal
15 coating. Solvent cleaning is not recommended, as the polymeric coating may be
16 damaged or residual solvent may outgas during the metal deposition. Therefore, one
17 preferred cleaning method involves immersing the polymeric coated substrate in an
18 ultrasonic aqueous solution.

19 After cleaning the polymeric coated substrates, the polymeric coated substrates
20 are positioned on a rack and placed in a metal deposition system. Application of the
21 metal over the polymeric coated substrate is described herein with regard to
22 magnetron sputtering equipment. Those of skill in the art will understand that the
23 metal may be applied by arc deposition, ion beam, e-beam evaporation, and other
24 methods known to those of skill in the art. There are many types of PVD systems
25 available which function and are operated similarly, as known to those of skill in the
26 art. A general process is disclosed herein, which may be modified as needed by those
27 of skill in the art. In the present method, the PVD system is a Leybold 2-700 P4
28 Magnetron Sputtering System. After placing the substrate on the rack, the rack is
29 positioned in the vacuum chamber of the PVD system, which is pumped down to a

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1 pressure ranging from about 5×10^{-4} to about 2×10^{-5} millitorr. If desired, the polymeric
2 coated substrates may be sputter etched to remove a thin layer of material from the
3 surface of the substrate. Sputter etching, or glow discharge, is well known in the art,
4 and is typically used to remove from about 10 to about 100 Å of surface material.
5 Thus, a surface free of any oxidation or contamination may be obtained before
6 depositing the metal. As those skilled in the art will understand, sputter etching
7 removes the microlayer of the substrate surface, exposing a fresh surface layer that
8 will bond better with the sputtered or vaporized target materials. Sputter etching is
9 typically performed in an inert gas environment, typically argon gas, through
10 bombardment of the substrate surface with charged ions of gas or target material. In
11 a preferred embodiment, the etching is performed at a voltage range of about 100 to
12 600 volts. It should be noted that such etching is not necessary to the method, as
13 bonding of the metal to the polymeric surface is possible without etching.

14 After sputter etching is performed, the polymeric coated substrates may be
15 heated using radiant heat lamps positioned within the vacuum chamber. Substrate
16 heating is generally used to enhance the adhesion of a metal coating to a surface of the
17 underlying substrate. In the present method, the heating temperatures are preferably
18 minimized in order to prevent damage to the underlying polymeric coating.
19 Accordingly, in the present method, the substrates are heated to temperatures ranging
20 from about 45° C to about 80° C for a period of about 5 minutes while in the PVD
21 vacuum chamber.

22 After heating the substrates, if performed, a metal coating is applied to the
23 polymeric coated surface. Surprisingly and unexpectedly, the metal coating adheres
24 so well to the polymeric coating on the substrate that it is possible to begin metal
25 deposition at higher pressure levels than are generally considered suitable, for
26 example, as high as 5×10^{-4} millitorr. A metal coating may be deposited in the
27 thickness range of from about 0.1 microns to about 1.5 microns. Coatings of greater
28 than about 5 microns are possible. For decorative and functional coatings, a thickness
29 of about 1.5 microns is preferred.

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1 In some embodiments, the color of the deposited metal may be changed by
2 introducing a reactive gas into the process chamber of the PVD system during the
3 deposition of the metal. For example, nitrogen introduced into the sputtering chamber
4 during deposition of the metal changes the color of the deposited metal film to yellow.
5 In such instances, RF sputtering must be used, or the substrates must be re-racked in
6 order to achieve a proper contact with the conductive surface of the substrate. Upon
7 completion of the metal deposition, the substrates are cooled and removed from the
8 vacuum chamber. Once the substrates are cooled, they are ready for use.

9 Suitable metallic materials for deposition onto the polymeric coating include,
10 but are not limited to, titanium, zirconium, chromium, gold, silver, platinum, copper,
11 aluminum, tin, molybdenum, boron, graphite, tantalum, tungsten, hafnium, and
12 combinations thereof. Alloys may also be deposited, including titanium-zirconium,
13 titanium-aluminum- vanadium, nickel-chrome, copper-silver, and aluminum-titanium.
14 Alloys are generally used when specific film characteristics are desired, such as a
15 specific sheet resistivity. Preferred coatings include titanium, zirconium, chromium,
16 titanium-aluminum, and aluminum titanium, due to their superior wear characteristics.

17 In some embodiments, an additional polymeric coating may be applied over
18 the metal coating to further enhance corrosion resistance, add color to the substrate,
19 or function as an additional electrical insulator. In such instances, the method of
20 application and polymerization of the polymeric precursor is performed in accordance
21 with the manufacturer's instructions, which may involve omitting the heating step.

22 Advantages of the present process include improved corrosion resistance and
23 chemical resistance of the substrate. These improvements will vary with the substrate.
24 The present method of coating substrates allows use of the less expensive substrates
25 that are prone to outgassing as the process effectively levels the surface, thus
26 preventing outgassing under a vacuum, which is used in most metal deposition
27 systems. Therefore, expensive and environmentally hazardous plating processes may
28 be eliminated. In some instances, the requirement for polishing substrates is also
29 eliminated, as the polymerized coating material provides a level, glossy finished

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1 level the surface. Fig. 3 illustrates another embodiment of an article 20, similar to
2 article 10, and including a further metal layer 18 disposed over polymeric layer 14.
3 Fig. 4 illustrates yet another embodiment of an article 30 which may be formed using
4 the present processes. Article 30 includes a substrate 12 with a rough surface 16 as
5 in the previous embodiments. A polymeric layer 14 is disposed on the surface 16 of
6 the substrate 12 in order to level the surface 16. A metallic layer 18 followed by a
7 polymeric layer 22 are disposed over the first polymeric layer 14.

8 WORKING EXAMPLES

9 EXAMPLE 1

10
11 Application of leveling polymeric coating. A brass substrate was placed on
12 an electrophoresis rack. Surface oxidation was removed from the substrate by
13 immersing the rack in a caustic solution, available under the product name
14 ELECTROCLEANER (trademark of MetalBond Technologies, LLC), which was followed
15 by a tap water rinse. The caustic solution was neutralized by placing the rack in an
16 acidic bath, followed by a deionized (DI) water rinse.

17 The rack was transferred to a polymeric bath maintained at a temperature of
18 about 75° F. The polymeric bath contained an aqueous solution/suspension of about
19 10 to about 14% by volume of a polyurethane available under the product name
20 TECHNICALAD V-BASE®. A DC voltage of about 100V was applied to the rack and
21 maintained for about 90 seconds.

22 The rack was transferred to a rinse bath, and allowed to remain in the rinse
23 bath for about 30 seconds. The rinse bath contained solvents, an emulsion stabilizer,
24 and de-ionized (DI) water. The rack was transferred to a DI water rinse bath and
25 allowed to remain in the DI water for about 30 seconds. The DI water rinse bath
26 included a "wetter," which promoted sheeting of the water from the substrate to
27 eliminate water spots.

28 The rack and substrate were then transferred into a convection oven. Once
29 reaching a temperature about 400° F, the substrates were allowed to remain at

1 temperature for about 45 minutes. At the end of the 45 minutes, the rack and substrate
2 were removed from the oven to cool to ambient temperature.

3 4 EXAMPLE 2

5 Application of PVD coating. A polyurethane coating was applied to a stainless
6 steel substrate according to the process outlined in Example 1.

7 After cooling, the substrate was placed on a rack. The rack was placed in the
8 process chamber of a Leybold 2-700 P4 Magnetron Sputtering System. The process
9 chamber was pumped down to a pressure of about 9×10^{-5} millitorr. Argon gas was
10 introduced to the process chamber until it reached pressure of about 5×10^{-3} millitorr.
11 The substrate was sputter etched at about 300 W for about 300 seconds (dynamic
12 mode) in order to remove any surface oxidation or contamination. A layer of chrome
13 was deposited on the surface of the etched substrate by magnetron sputter deposition
14 at 2000 W for about 10 minutes (dynamic mode) to reach a thickness of about 0.15
15 μm . The chamber pressure was brought to atmospheric pressure, and the substrate
16 was removed from the system.

17 The adhesion of the PVD coating to the surface of the polymeric material was
18 excellent (test BS 3900 E61974, rating 0).

19 The appearance of the metal coating was lustrous and highly reflective as
20 measured in a standard L.A.B. test, using a Minolta CM-5031 spectrophotometer and
21 a D-65 light source. The L.A.B. readings of the substrate surface were: L:75.5;
22 A:1.1; B:4.4.

23 24 EXAMPLE 3

25 Application of clear protective polymeric coating. A substrate was coated with
26 a polyurethane layer and a PVD layer according to Examples 1 and 2

27 The PVD coated substrate was then placed on an electrophoresis rack. Surface
28 oxidation was removed from the substrate by immersing the rack in
29 ELECTROCLEANER™, which was followed by a tap water rinse. The caustic solution

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1 was neutralized by placing the rack in an acidic bath, followed by a DI water rinse.
2 The rack was transferred to into a polymeric bath maintained at a temperature of
3 about 75° F. The polymeric bath contained an aqueous solution/suspension of about
4 10 percent to about 14 percent by volume of a polyurethane available under the
5 product name TECHNICLAD HARP (available from MetalBond Technologies, LLC). A
6 DC voltage of about 100V was applied to the rack and maintained for about 90
7 seconds. The rack was transferred to a rinse bath, and allowed to remain in the rinse
8 bath for about 30 seconds. The rinse bath contained solvent, emulsion stabilizer, and
9 DI water. The rack was transferred to a DI water rinse bath and allowed to remain in
10 the DI water for about 30 seconds. The DI water rinse bath included a "wetter," which
11 promoted sheeting of the water from the substrate to eliminate water spots. The rack
12 and substrate were then transferred into a convection oven. Once reaching a
13 temperature about 320° F, the substrates were allowed to remain at that temperature
14 for about 12 minutes. At the end of the 12 minutes, the rack and substrate were
15 removed from the oven to cool.

16 It will be understood that various modifications may be made to the
17 embodiments disclosed herein. These and other changes can be made provided the
18 functioning and operation thereof are not adversely affected. Therefore, the above
19 description should not be construed as limiting, but merely as exemplifications of a
20 preferred embodiment. Those skilled in the art will envision other modifications
21 within the scope spirit of the invention.

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